PRECOMBUSTION CONTROL OPTIONS FOR AIR TOXICS

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INTRODUCTION

Coal cleaning reduces the ash and sulfur content of coal by removing ash-forming and sulfur-bearing minerals. Coal cleaning can also reduce the concentration of most of the elements named as hazardous air pollutants in the 1990 Amendments to the Clean Air Act because many of these elements are associated with mineral matter. For example, arsenic is commonly associated with pyrite; cadmium with sphalerite; chromium with clay minerals; mercury with pyrite and cinnabar; nickel with millerite, pyrite, and other sulfides; and selenium with lead selenide, pyrite, and other sulfides (Finkelman, 1980). There are also cases in which some of these elements are organically bound. Just as both organic and pyritic sulfur can be found in the same coal, the same trace element may be both organically bound and present as part of a mineral in the same coal. Organically bound trace elements are not removed by currently used methods of cleaning coal.

Trace elements removed by coal cleaning will not be released into the atmosphere during combustion. Also, coal cleaning reduces the ash content of the coal and increases the heating value, reducing transportation costs and increasing boiler efficiency. Finally, coal cleaning provides other environmental benefits by reducing the sulfur dioxide emissions potential of the coal and the amount of ash for collection and disposal.

As an air toxics control measure, coal cleaning offers several advantages to utilities. Because physical coal cleaning is a relatively inexpensive technology, it may prove to be the lowest-cost control option in many cases. Also, coal cleaning is currently the only commercially available control technology for the highly volatile trace element mercury. Finally, removing trace elements before combustion reduces the concentration of these elements in utility solid wastes, reducing possible long-term environmental liability.

TRACE ELEMENT REDUCTION BY CONVENTIONAL CLEANING

In the US, work by CQ Inc., Southern Company Services, Inc. (SCS), Consolidation Coal Company (CONSOL), and Bituminous Coal Research Inc. (BCR) has demonstrated that conventional methods of coal cleaning can produce large reductions in the concentration of many trace elements (Akers and Dospoy, 1993; CQ Inc. and SCS, 1993; DeVito et al., 1993; and Ford and Price, 1982). Combined, these sources provide trace element reduction data from 16 commercial and ten commercial-scale cleaning tests. This data is summarized for arsenic and mercury in Table 1. As no attempt was made to enhance removal of any trace element, these results are representative of trace element reductions that occur as a by-product of cleaning for ash and sulfur reduction.

The data in Table 1 demonstrate that physical coal cleaning is effective in reducing the concentration of these two trace elements, although the degree of effectiveness varies. For example, arsenic reduction varies from 20 to 85 percent and mercury reduction from -191 (an increase) to 78 percent. Part of the observed variability in trace element reduction is caused by poor analytical precision. The accurate measurement of elements present in trace concentrations in coal is challenging and even well qualified laboratories can produce faulty results (Akers et al., 1990). However, most of the variability appears to relate to the interactions between the total amount of mineral matter removed by cleaning, the method by which the coal is cleaned, and the mode of occurrence of the trace element bearing-mineral matter.

The primary economic motive for cleaning coal is to remove ash-forming mineral matter to reduce coal transportation costs, lower ash collection, handling and disposal costs, and increase combustion efficiency. Coals are cleaned to a variety of ash levels to meet local and regional market demands. The ash reduction achieved by a cleaning plant is directly related to the total amount of mineral matter removed. Not surprisingly, trace element reduction tends to increase with ash reduction. However, factors other than ash reduction impact the reduction of many elements including the degree of liberation of the trace element bearing mineral and the ability of the coal cleaning equipment utilized to remove the mineral.

Mineral matter occurs in coal in a variety of forms. For example, pyrite, the most studied coal-associated mineral, can occur as anything from a massive fracture fill several centimeters in size to discrete euhedral crystals a few microns in size. Some conventional coal cleaning operations crush the raw coal before cleaning to protect equipment from oversized material and to liberate ash- or sulfur-bearing minerals. While crushing is minimized to avoid producing excess fines, it can liberate larger minerals forms. It can also liberate trace element-bearing mineral matter.

CQ Inc. performed a washability study of Kentucky No. 11 Seam coal. During this study, a comparison was made of uncrushed coal with coal crushed to 9.5 mm topsize. In this case, additional arsenic liberation occurs when the raw coal is crushed to a topsize of 9.5 mm. For example, cleaning the uncrushed coal at 90 percent energy recovery produces an 86 percent arsenic reduction, while cleaning the crushed coal at the same energy recovery produces a 97 percent arsenic reduction. In this example, crushing increased the liberation of the arsenic-bearing mineral(s) in the coal allowing additional quantities to be removed without any sacrifice of energy recovery.

The type of equipment used in a cleaning plant can also affect trace element reduction. Table 2 contains a comparison of a heavy-media cyclone and froth flotation for trace element reduction. In this case, Pratt Seam coal from Alabama was cleaned by both technologies. Here, chromium reduction is roughly proportional to ash reduction for both cleaning devices; however, while mercury is reduced by the heavy-media cyclone, it is increased by froth flotation.

The comparison of froth flotation to heavy-media cycloning illustrates the concept that physical cleaning processes do not remove trace elements as such, but rather remove trace element-bearing minerals. Mercury commonly occurs in coal within the structure of the mineral pyrite. As pyrite is a very dense mineral, it is easily removed by a density-based process such as a heavy-media cyclone. However, cleaning processes such as froth flotation remove minerals based on surface characteristics. Because coal and pyrite have similar surface characteristics, conventional froth flotation may not provide high reductions of either pyrite or pyrite-associated trace elements such as mercury.

TRACE ELEMENT REDUCTION BY ADVANCED CLEANING

Advanced coal cleaning technologies may offer advantages over conventional technologies in reducing trace elements. Advanced processes typically involve crushing coal to increase the chance of liberating sulfur-bearing and ash-forming mineral matter, possibly also liberating trace element-bearing mineral matter. Also, advanced processes are specifically designed to clean fine-sized coal, making them more efficient than conventional processes in removing mineral matter from this material.

In an evaluation of Sewickley Seam coal, CQ Inc. compared an advanced coal cleaning process developed by Custom Coals International to conventional coal cleaning techniques (Akers and Dospoy, 1993). The Custom Coals' process is characterized by several innovative components including a fine-coal heavy-media cyclone separation circuit. A conventional coal cleaning plant using heavy-media vessels and water-only cyclones was used for comparison. As part of this evaluation, extensive washability and liberation tests were performed on the coal. CQ Inc. engineers developed computer models of a conventional coal cleaning plant and a plant using the advanced process with middlings crushing for liberation. This information was used to produce a laboratory-simulated clean coal by combining the appropriate size and density fractions of the raw coal in the proportions predicted by the models to produce both the conventional and the advanced clean coal.

The results of this evaluation are presented in Table 3. Conventional cleaning techniques reduced the concentration of antimony, arsenic, chromium, cobalt, lead, mercury, and nickel and advanced techniques provided a further reduction in all cases except mercury. For example, conventional cleaning reduced the arsenic concentration of the coal from 14 to 7 ppm, while advanced cleaning provided a further reduction to 4 ppm.

CONCLUSIONS

Coal cleaning techniques are effective in removing ash-forming mineral matter along with many mineral-associated trace elements from coal. Data gathered from commercial and commercial-scale cleaning tests indicate that trace element reduction tends to increase as ash reduction increases. However, factors such as the mode of occurrence of the trace

element-bearing mineral and the type of cleaning equipment employed also affect trace element reduction. Furthermore, there is some evidence that advanced coal cleaning processes can provide higher reductions of some trace elements than conventional processes. Knowledge of the interplay between the characteristics of the trace element-bearing mineral and various types of coal cleaning equipment can be used to enhance trace element removal during coal cleaning.

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Table 1. Trace Element Reduction by Conventional Coal Cleaning

Seam	Data Source	Ash Reduction (%)	Arsenic Reduction (%)	Mercury Reduction (%)
Central App. A	CONSOL	87	58	22
Central App. B	CONSOL	88	49	39
Illinois No. 6	CONSOL	87	62	60
Pittsburgh - A	CONSOL	52	68	33
Pittsburgh - B	CONSOL	79	74	50
Pittsburgh - C	CONSOL	82	75	30
Pittsburgh - D	CONSOL	76	83	12
Pittsburgh - E	CONSOL	78	63	41
Pittsburgh	SCS	84	81	42
Upper Freeport	SCS	24	40	-191
Lower Kittanning	BCR	74	72	38
Sewickley	BCR	65	51	25
Pittsburgh	BCR	69	61	27
Pittsburgh	BCR	34	30	14
Illinois No. 6	BCR	57	20	12
Kentucky No. 9&14	BCR	51	46	24
Pratt/Utley	CQ Inc.	75	43	39
Pratt	CQ Inc.	66	42	22
Utley	CQ Inc.	43	29	26
Pratt	CQ Inc.	75	28	45
Upper Freeport	CQ Inc.	83	83	78
Upper Freeport	CQ Inc.	86	85	76
Illinois 2,3,5	CQ Inc.	61	39	28
Illinois 2,3,5	CQ Inc.	57	54	50
Kentucky No. 11	CQ Inc.	86	66	--
Kentucky No. 11	CQ Inc.	90	43	48

CONSOL - Consolidation Coal Company
SCS - Southern Company Services, Inc.
BCR - Bituminous Coal Research
App - Appalachian

Table 2. **Equipment Performance Comparison (Percent Reductions)**

	Heavy-Media Cyclone	Froth Flotation
Ash	70	62
Chromium	63	56
Mercury	26	-20

Table 3. **Conventional and Advanced Cleaning (ppm except where noted)**

	Raw	Conventional Cleaning	Custom Coal Advanced Process
Ash Content (Wt %)	29.2	15.2	14.0
Antimony	0.80	0.48	0.26
Arsenic	14.0	7.2	3.5
Cadmium	0.20	0.63	0.34
Chromium	16.07	8.35	8.22
Cobalt	0.27	0.24	0.22
Lead	14.73	6.96	6.16
Mercury	0.16	0.14	0.14
Nickel	13.39	9.13	8.21
Selenium	1.14	1.54	1.24